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IMAGE DYNAMIC MEASUREMENT SYSTEM (IDMS-2) FOR FLIGHT SIMULATION FIDELITY VERIFICATION

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Abstract

The fidelity of human-in-the-loop flight simulators is critically dependent upon maintaining a short time interval in the response of the motion and visual cues to a change in the simulated aircraft response. The delay in the visual and motion cues is of particular concern in research and development flight simulators because the pilot perceives the simulated aircraft response and performance primarily through these simulation cues. While the delay in the motion base response can be monitored with accelerometers and other sensors, the measurement of the delay in the visual system response time requires an instrument for analyzing the video data in real-time. The Image Dynamic Measurement System, Mark II (IDMS-2) has been developed at NASA's Ames Research Center to analyze the output video of an image generator and to produce analog and digital outputs proportional to the position of a predefined target image. The IDMS-2 is designed to support a wide variety of video sources and scan rates and has an adaptive timing system that allows for analysis of the target image during each video field, independent of scan rate or interlace factor. In addition, the logic contained within the IDMS-2 prevents erroneous data from being generated if the instrument is not configured properly for the video source being analyzed. In this paper, the design and implementation of the IDMS-2 instrument will be presented. The use of the IDMS-2 in verifying the visual cueing fidelity of the Vertical Motion Simulator at Ames Research Center will also be discussed.

Introduction

In order to quantify the perceived response of a simulated aircraft based on the simulator's visual system, it is necessary to measure the visual system's throughput delay characteristics by electronically
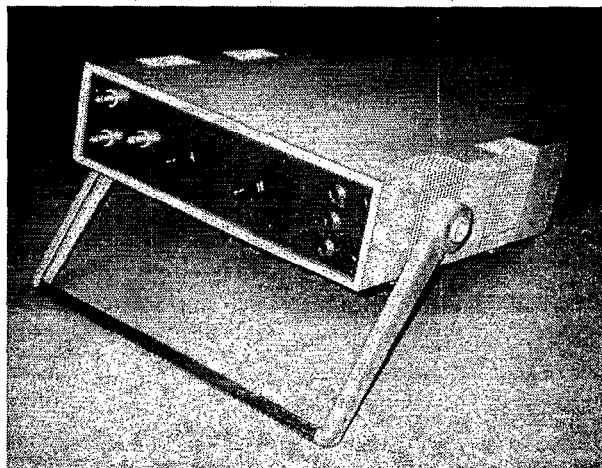

Figure 1: The portable version of the IDMS-2 developed by Logicon Information Systems and Services for NASA's Vertical Motion Simulator facility at Ames Research Center.
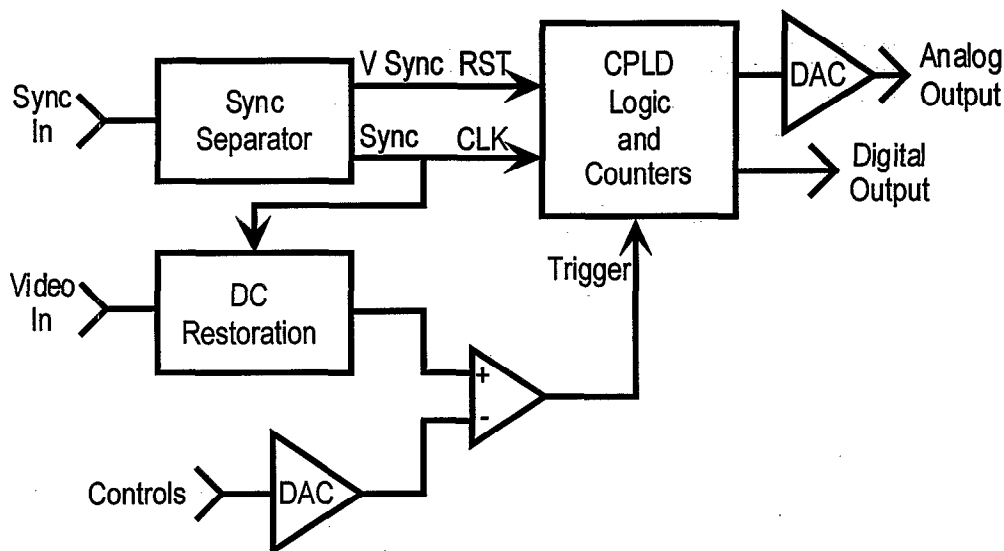
Figure 2: Schematic diagram of the functional blocks that make up the IDMS-2 instrument. Both the threshold voltage generator and the output stage gain are controlled via front panel controls.

tracking the motion of visual targets. At NASA's Ames Research Center, the Image Dynamic Measurement System, Mark II (IDMS-2) has been developed as an instrument for determining the position of these visual targets. In conjunction with a cross-correlation analysis technique, the delay in the generation of the visual targets can be compared to the visual system command signal in the mathematical model or other cueing devices. The instrument has been developed in both rack-mount and portable packages (Fig. 1).

Instrument Description

The IDMS-2 is designed to analyze NTSC and RGB video signals and generate analog and digital representations of the position of a target. The target for this instrument is one-dimensional in that it is made up of a transition during a vertical scan from a dark field to a light field. The IDMS-2 has the flexibility to handle different types of video sources and thus has separate inputs for video and sync signals in order to accommodate RGB video systems with separate sync signals. NTSC video or RGB video with sync-on-green have composite video sync and data on the same

channel, and the video signal should be fed to both inputs[1]. To allow the IDMS-2 to be used with a variety of coaxial cables, the inputs of the instrument have high impedance. Each input signal cable can then be externally terminated into its characteristic impedance as required by the particular application.

The IDMS-2 consists of several functional blocks, including a sync separation circuit, a video discrimination circuit, and an analog and digital output processor (Fig. 2). While the functional blocks that handle analog signals use discrete components, all of the digital logic is contained in a Complex Programmable Logic Device, or CPLD[2]. The Xilinx XC9500[3] series CPLD was selected for this instrument because it provides excellent flexibility due to its In-System Programming feature[4]. Since the IDMS-2 is a research instrument, the ability to reprogram the instrument to meet future requirements is highly valuable. However, the IDMS-2 has been designed not to require any user programming for normal operation.

The sync separation circuit generates separate signals for vertical and horizontal sync from the signal applied to the Sync In input. The sync separation circuit

has a horizontal line scan rate in excess of 150kHz, and thus has sufficient bandwidth to process video signals from high-resolution image generators. The IDMS-2 uses the vertical sync to reset a set of horizontal line counters that are clocked by the horizontal sync signal. When a dark to bright transition is detected by the video discrimination circuit, the current horizontal line count is latched to a DAC for the analog output and a separate set of latching buffers for the digital output.

The video discrimination circuit has several components, including a DC restoration circuit, a programmable threshold voltage, and a comparator. The DC restoration circuit detects the "dark" level at the beginning of each line of video data. The comparator stage compares the difference between the video level relative to the "dark" level and the user selected threshold level. The threshold level is set by a DAC controlled by a sixteen position rotary switch on the front panel of the instrument. When the video data exceeds the threshold voltage within any video line, the comparator sends a trigger signal to the output processor.

The output processor stage relies on a 12-bit digital counter driven by the horizontal sync signal to count the number of horizontal lines since the last vertical sync signal was asserted. When the comparator in the video discrimination circuit observes a transition, the trigger from the comparator fires a one-shot that clocks the current contents of the counter into a set of latches for the 12 bit digital output.

The analog output is derived from a 12 bit latching DAC. The output range is specified in terms of producing a 10 Volt maximum output for a range of lines per field: 4096, 2048, 1024, 512, and 256. For each step in this range, the value of the digital counter is digitally multiplied by 2. Thus, the dynamic data of the counter will be in the top bits of the DAC. Therefore, taking the 256 lines per field setting as an example, only the lower 8 bits of the counter will be significant. In order to generate the 10 Volt output on the DAC, these 8 bits of data have to be shifted to the top 8 bits of the DAC. Since this operation is done digitally, a separate output stage with programmable gain is not necessary.

The IDMS-2 processes each field of video data presented, independent of whether the field is part of an interlaced or non-interlaced frame (a frame is one complete video picture). To eliminate any confusion in determining the location of the target during a scan of a video field, only one transition is allowed per field. The one-shot that controls the latches is not reset until a vertical reset is generated by the sync separation circuit at the end of the video field. Therefore, the bandwidth for updating the position data is the video field rate. For example, if an image generator is producing 30 frames per second and presents each frame as two interlaced fields, position data generated by the IDMS-2 will be updated at 60 Hz. In addition, the digital and analog outputs are updated immediately upon detection of a transition and are held constant until the next transition is detected in a subsequent field.

Since the target detection is based upon observing the brightness of the video signal, certain types of video signals are not compatible with the IDMS-2. As a specific example, the IDMS-2 can not properly process NTSC signals that have closed captioning data embedded in the first few lines of each field. In the case of closed captioning, the embedded data has the same amplitude as the maximum brightness level for NTSC video, thus generating a false trigger early in each vertical field scan. The IDMS-2 is also not equipped to process video signals with digital sync signals, such as VGA or serial digital video.

Operation

To configure the IDMS-2 for normal operation, the video signal to be analyzed is first connected to the inputs of the IDMS-2. Depending upon the configuration of the flight simulation facility, the connection to the IDMS-2 can be accomplished by splicing into the existing lines to the cockpit display units or replicating the video signal with either a distribution amplifier or a video matrix switch (Fig. 3). The output of the IDMS-2 is connected to a data acquisition computer that also monitors the command signal to move the target on the image generator. Again depending upon the configuration of the simulator facility, the data acquisition system could either be the

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Termination

IDMS-2 Image Dynamic Measurement System

Sync In

Video In

Analog

Trigger Level

Max Lines/Field

Trigger

Overflow

Power

Green
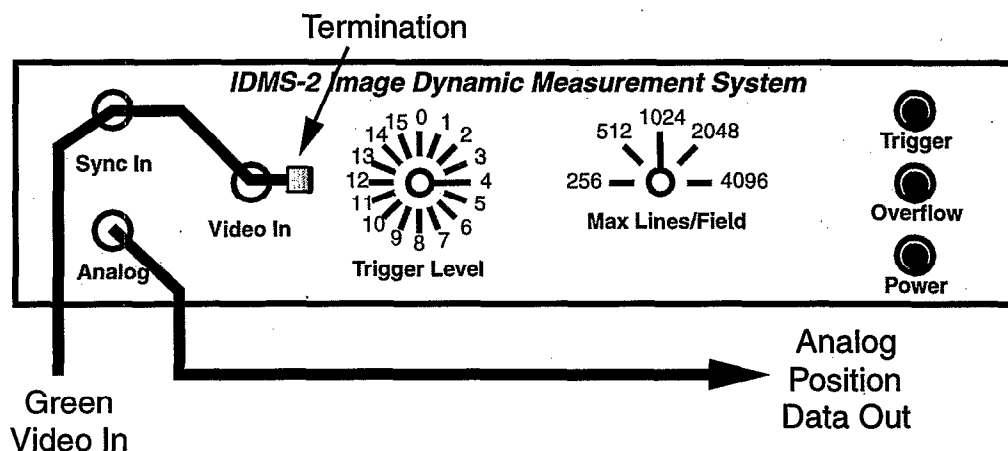Video In

Analog
Position
Data Out

Figure 3: Typical connection diagram for the IDMS-2 instrument when analyzing a "sync-on-green" RGB video signal source.

host computer that operates the simulator or a separate piece of dedicated data acquisition hardware.

Once the IDMS-2 is physically connected, the user then configures the threshold level and number of field lines to process. The front panel Trigger Level selector allows for the choice of one of sixteen linearly increasing threshold levels. Valid transitions are best discriminated from the background dark level and other noise sources by selecting the highest threshold level that is still less than the video level of the bright portion of the field. If the behavior of the threshold detector needs to be checked, the two inputs to the internal comparator of the IDMS-2 are available as test points on the rear of the instrument. With these test points, the proper operation of the threshold voltage DAC and the DC restoration circuit can be checked, as well as letting the user monitor the input video data without disturbing the input connections to the instrument.

In addition, the Trigger lamp on the front of the IDMS-2 instrument can be used as a visual indication that the transitions are being detected in each field displayed. If the Trigger lamp flashes irregularly, it is an indication that the threshold level may be too high, or that the transitions are not being generated in each field.

The other front panel indicator is the Overflow lamp. The overflow indication can result from one of two conditions associated with the digital data for the output DAC overflowing. In either case, the number of lines in the video field has to be less than the maximum number of lines selected on the front panel selector in order for the IDMS-2 to generate an Overflow indication. In the first case, the transition in the video level occurs at a line greater than the maximum number selected, while in the second case, no transition occurs at all because of an all black field, for example. However, in the case of an all black field, no Trigger indication will be seen. In the event of an overflow condition, the DAC output is set to maximum (10 volts). The maximum output level is held until the next valid trigger is observed in a subsequent field. The overflow indication has no effect on the digital output since it has 12-bit resolution and simply counts the number of lines since the last vertical reset to the video transition.

Discussion

The IDMS-2 has been fully integrated and tested at the Vertical Motion Simulator (VMS)[5]. The VMS is the world's largest flight simulator motion base, with a vertical displacement of 60 feet and a lateral displacement of 40 feet (Fig. 4). The out-the-window

Figure 5: Schematic representation of the relative positions of the side viewing eyepoint on the simulated aircraft and the target object used for a visual throughput test.
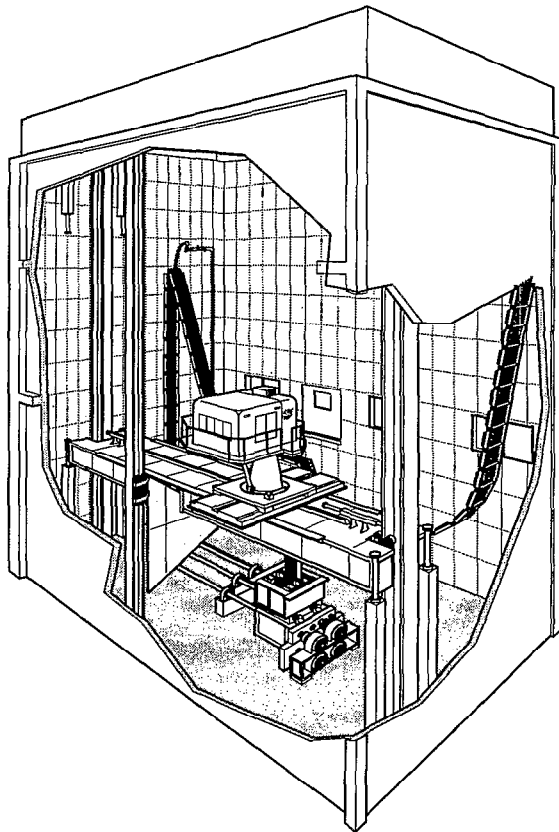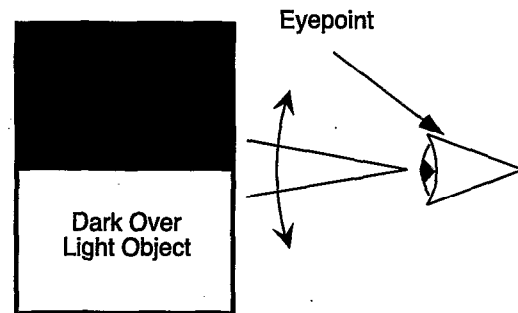

Figure 4: Cutaway drawing of NASA's Vertical Motion Simulator (VMS) tower.

visual scenes are generated by one of two Evans and Sutherland image generators (an ESIG-3000 or an ESIG-4530) that are driven via a dedicated Ethernet network by a real-time executive running on Compaq Alpha processors. The real-time executive manages the math model of the simulated aircraft, the I/O for the motion base and cockpit instrumentation, and the collection and recording of various model parameters during a simulation.

In addition to the image generators for the out-the-window scene, several SGI workstations are also available to generate HUD (head's-up displays) and HDD (head's-down display) graphics and are also connected to the real-time host via the same dedicated Ethernet network. All of the video sources for the laboratory are selectable through a video switch matrix

and can be processed and mixed for a variety of researcher and pilot applications.

Since the IDMS-2 is to be used to determine the total delay in the generation of visual cues from changes in simulated aircraft position and attitude, the video target for the instrument has to be generated using the standard out-the-window scene configuration of the image generator. The only special requirement in the image generator configuration is the placement of a tower-like object in the image generator's database that has a dark top and a white bottom (Fig. 5). The aircraft's position and attitude is set so that the eyepoint is directly in front of the tower object and is so close to the tower that it completely fills the field of view in both the horizontal and vertical directions. The actual axis to be tested depends upon the requirements of the simulator fidelity test, but typically vertical and pitch axes are tested using the forward looking eyepoint of the center window of the image generator, while roll and lateral axes can be tested using a side viewing eyepoint.

For the characterization discussed in this paper, a generic helicopter model is used and the fidelity of the cues for the roll axis is studied by driving the motion base and visual system with the real-time helicopter model solely along the axis in question. In order to factor in the total delay in the presentation of the visual cues, the video is monitored at the last distribution amplifier before entering the cockpit. Thus, the delay in the visual cue will include the host computer, the real-

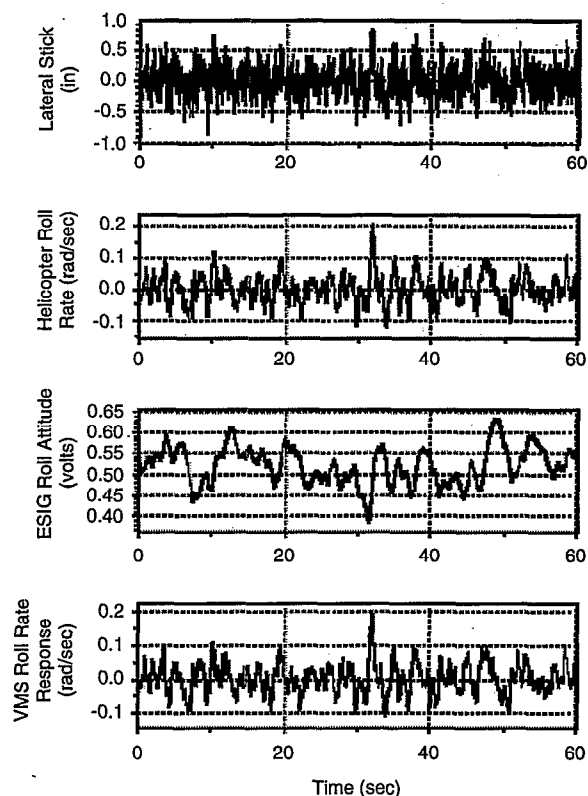American Institute of Aeronautics and Astronautics

Figure 6: Time histories of the raw data from a roll rate fidelity study for the VMS. Shown are the lateral input command signal and the corresponding roll behavior computed in the model and measured in both the visual and motion systems.

Figure 7: Comparison of frequency response of various roll rates to lateral stick input command. Note that preceived roll rates from the visual and motion cues are quite similar in this characterization test of the VMS.

time network, the image generator, all of the video distribution, and the video switch matrix.

The Evans and Sutherland ESIG-3000 image generator used in these tests generates RGB video with sync information on the green channel. Thus, the green video signal is used as the input to the IDMS-2 and the analog output of the instrument is connected to an analog to digital converter (ADC) channel in the real-time I/O system. The ADC channel is sampled during each cycle of the real-time system, which has a maximum frame rate in excess of 100 Hz, depending
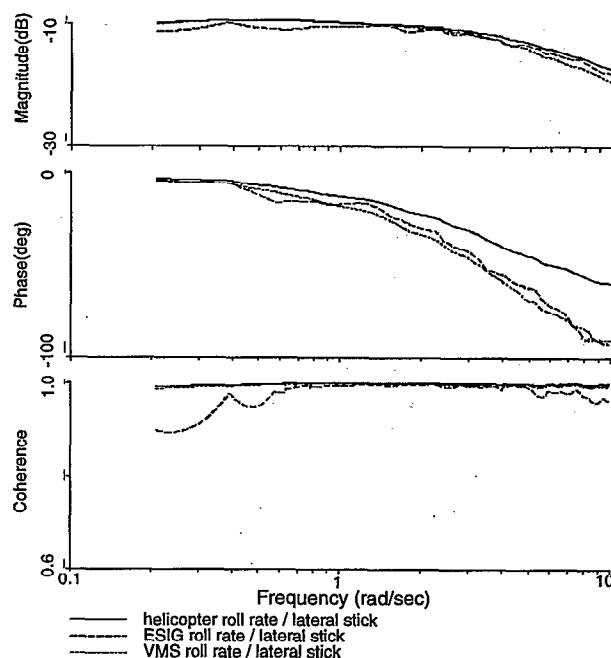
upon simulation complexity and operational requirements.

To determine the simulated aircraft response characteristics, the perceived visual cues are measured by the IDMS-2 and the effective image response time of the ESIG-3000 is measured. In addition, measurements of the perceived motion cues of the VMS motion base are made simultaneously for comparison with the visual cue data. A white noise source with a Gaussian distribution of the energy over the frequency spectrum is fed into the lateral stick input of a helicopter with a roll damping characteristics of 4 rad/sec in a roll rate command system. The time history of the white noise control inputs, helicopter roll rate, roll attitude video measurement, and the roll rate motion response are

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shown in Fig. 6. The frequency response of the helicopter roll rate, scaled ESIG roll rate response (obtained by using the derivative feature of CIFER[6]), and the roll motion response versus the lateral stick inputs are shown in Fig. 7. The coherence of these frequency responses shows that the data within the test range, i. e., up to 10 rad/sec, are highly linear. The phase response of the ESIG roll rate response, which shows an approximate delay of 60 msec, matches well with the VMS roll motion response as recommended by Ref. 7. The effective handling qualities of the simulated helicopter can then be determined from the visual roll rate response to be 2.8 rad/sec with a time delay of 0.046 sec, which is desirable for a tracking task according to Ref. 8.

Conclusions

The Image Dynamic Measurement System, Mark II (IDMS-2) has been developed to provide a robust, programmable instrument for generating a signal proportional to the position of a target on a visual display. The design incorporates a number of features that provide the flexibility to handle video data from a number of different image generators, as well as minimizing the number of field adjustments necessary to keep the instrument operating properly. In addition, the use of a white noise distribution for the lateral command signal to the helicopter model and the corresponding roll response generated by the visual system allows for a thorough analysis of the frequency response and delay of the visual cueing system of a flight simulator. Both the motion and visual systems of the Vertical Motion Simulator have demonstrated similar delays in cue response. However, the performance of these systems is a function of the complexity of the simulation, thus a flexible and adaptable instrument such as the IDMS-2 reduces the difficulty in determining the fidelity of the visual cues in a particular simulation.

Acknowledgments

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